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# AVAILABILITY AND QUALITY OF GROUND WATER IN THE PIEDMONT PROVINCE OF VIRGINIA

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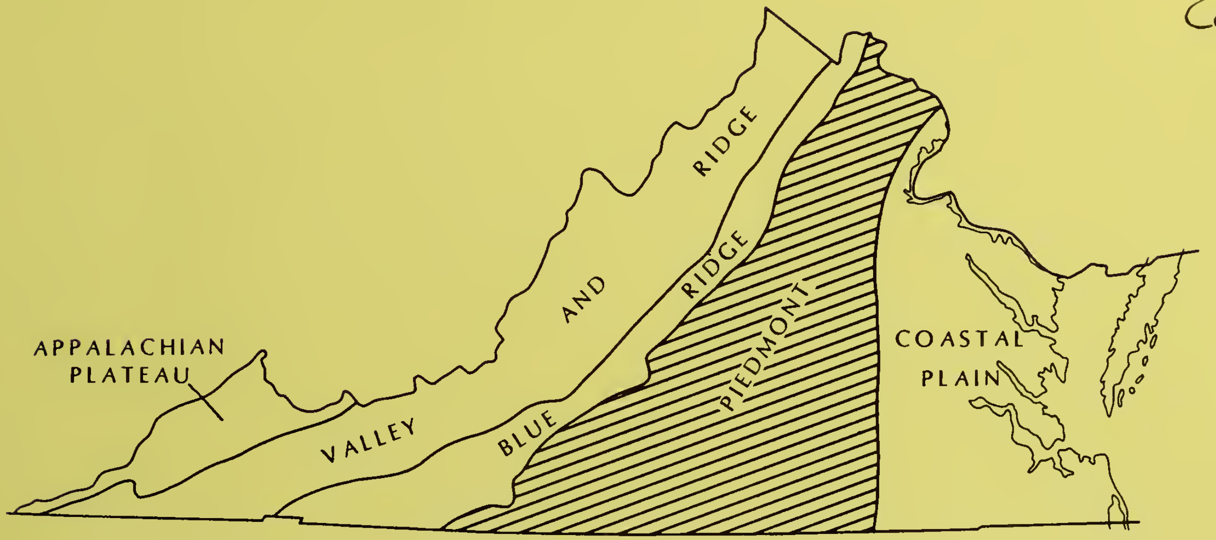


U.S. GEOLOGICAL SURVEY

Water Resources Investigations Report 85-4235

Prepared in cooperation with the
VIRGINIA STATE WATER CONTROL BOARD

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Richmond, Virginia

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

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## CONVERSION TABLE

The following factors may be used to convert inch-pound units to metric (International System) units.

| Multiply inch-pound unit | By | To obtain metric unit |
| --- | --- | --- |
| inches (in) | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meters (m) |

# AVAILABILITY AND QUALITY OF GROUND WATER IN THE PIEDMONT PROVINCE OF VIRGINIA

By John D. Powell and Joseph M. Abe

## ABSTRACT

The Piedmont Province of Virginia has an ample supply of ground water, perhaps as much as 1.5 billion gallons are in storage per square mile, generally suitable for domestic and small supply needs. The source of this ground water is precipitation.

Ground water within the crystalline rocks of the Piedmont is stored in the pore spaces of the regolith and in fractures in the underlying bedrock. Water within the sedimentary rocks of the sedimentary basins is stored in bedding planes, fractures, and in pore spaces in the rock, and in the regolith. Well yields can be maximized in both terranes by constructing wells along lineaments and in valleys.

Ground water in the crystalline rocks is generally slightly mineralized and acidic (pH <7.0). Ground water in the sedimentary rocks is more mineralized and basic (pH >7.0). Dissolved solids concentration in deep wells (>500 feet) in sedimentary rock may exceed tolerable limits. Land disposal of solid wastes and sewage from domestic septic systems present the major threat to ground-water quality.

A greater understanding of the ground-water system in the Virginia Piedmont could be used to anticipate future shortages so that preventive measures could be implemented to protect the ground-water reservoir.

## INTRODUCTION

The Piedmont Province of Virginia, which includes parts of 40 counties, has the largest area of any physiographic province within the Commonwealth of Virginia (fig. 1). Bordered on the west by the Blue Ridge Province and on the east by the Coastal Plain Province, the Piedmont encompasses about 40 percent of Virginia's land area. The Piedmont is predominantly a rural setting. Estimates of land use representing areas in both the northern and southern Piedmont are provided in table 1. Forest and pasture are the major land uses in the Piedmont. According to the 1980 census, approximately 41 percent of the state's population lives in the Piedmont (U.S. Department of Commerce, 1981). Excluding independent cities and water use in thermoelectric plants, estimated water use in the Piedmont during 1980 was 272 million gallons per day (Kull, 1983). Approximately 116 million gallons per day of this amount (43 percent) is ground water. A breakdown of water use by county is provided in table 2.

In recent years, the crystalline rocks of the Piedmont have come under scrutiny as a potential site for the disposal of high-level and low-level radioactive waste and hazardous chemicals. In the southern Piedmont of Virginia, the environmental impact of the mining and processing of uranium ore is currently under investigation. All these issues have potential for disrupting, to some extent, the ground-water resources of the Piedmont and make an understanding of the availability and quality of ground water more critical.

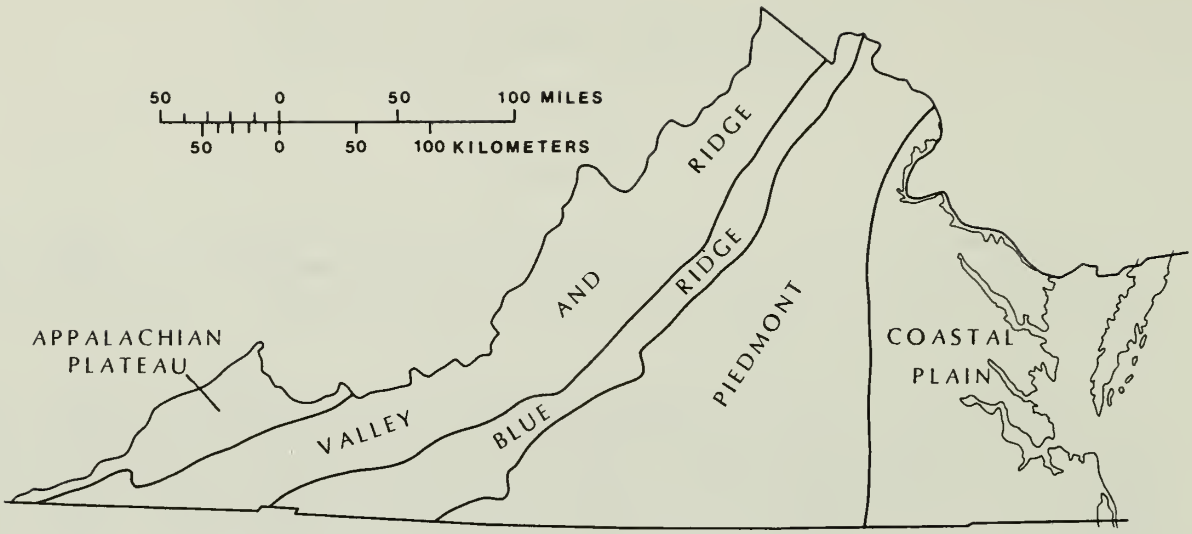


Figure 1.-- Physiographic provinces of Virginia.

Table 1.--Land use in the Piedmont Province of Virginia. [Northern Piedmont includes Culpeper, Fauquier, Madison, Orange, and Rappahannock Counties. Southern Piedmont includes Amelia, Buckingham, Charlotte, Cumberland, Lunenburg, Nottoway, and Prince Edward Counties. Category of land use titled "Other" includes urban, suburban, and unclassified areas. Land use data provided by Virginia Commonwealth Data Base]

| | Northern Piedmont | | Southern Piedmont | |
|---|---|---|---|---|
| Land Use | Acreage | Percent | Acreage | Percent |
| Forest | 670,788.9 | 53.1 | 1,181,469 | 65.5 |
| Water | 1,910.8 | 0.2 | 9,484 | 0.5 |
| Cropland | 141,594.5 | 11.2 | 241,064 | 13.4 |
| Pasture & range | 383,470.8 | 30.4 | 328,857 | 18.2 |
| Other | 63,804.5 | 5.1 | 44,021 | 2.4 |
| Total | 1,261,569.5 | 100.0 | 1,804,895 | 100.0 |

Table 2. Estimated water use in Piedmont Province of Virginia by county [in million gallons per day] (from Kull, 1983).

| | GROUND WATER | SURFACE WATER |
|---|---|---|
| Albemarle | 3.663 | 3.598 |
| Amelia | .935 | .812 |
| Amherst | 6.418 | 1.402 |
| Appomattox | 2.323 | .359 |
| Bedford | 13.378 | .701 |
| Brunswick | 1.629 | 1.615 |
| Buckingham | 1.342 | .203 |
| Campbell | 4.533 | 8.454 |
| Caroline | 2.319 | .028 |
| Charlotte | 1.289 | 2.292 |
| Chesterfield | 1.585 | 38.666 |
| Culpeper | 1.743 | 1.688 |
| Cumberland | .840 | .197 |
| Dinwiddie | 2.472 | 1.554 |
| Fairfax | 7.892 | 56.460 |
| Fauquier | 3.083 | 1.630 |
| Fluvanna | 1.351 | 0.0 |
| Franklin | 2.994 | 2.230 |
| Goochland | 1.146 | .351 |
| Greene | .676 | .264 |
| Greensville | .973 | 0.0 |
| Halifax | 3.204 | 1.692 |
| Hanover | 5.146 | 1.742 |
| Henry | 7.305 | 2.218 |
| Loudoun | 3.990 | 1.824 |
| Louisa | 1.875 | .227 |
| Lunenburg | .808 | 1.696 |
| Madison | 1.040 | .650 |
| Mecklenburg | 2.746 | 3.936 |
| Nelson | 1.182 | .203 |
| Notoway | .883 | 1.701 |
| Orange | 2.329 | .811 |
| Patrick | 2.181 | .700 |
| Pittsylvania | 6.578 | 4.610 |
| Powhatan | 1.377 | .294 |
| Prince Edward | 1.199 | .810 |
| Prince William | 6.458 | 7.835 |
| Rappahanock | .622 | .158 |
| Spotsylvania | 2.429 | .960 |
| Stafford | 2.244 | 1.360 |
| TOTAL | 116.180 | 155.931 |

## Purpose and Scope

The purpose of this report is to describe the availability and quality of ground water within the Piedmont Province of Virginia. Information from previously published reports concerning Virginia as well as adjoining states is summarized to meet this objective.

## Previous Studies

Ground-water studies in the Virginia Piedmont Province include LeGrande (1967), Heath (1984), and Trainer and Watkins (1975). Studies concentrating on Virginia include Commonwealth of Virginia State Water Control Board (1978) and several local studies: Dawson and Davidson (1979), LeGrand (1960), and Murphy (1979). Similar investigations in adjacent and nearby states are, from Maryland: Nutter and Otton (1969), Nutter (1977), Nutter (1975), Otton (1981), and Richardson (1982); from North Carolina: Bain and Brown (1981), Daniel and Sharpless (1983), and Heath (1980); from Pennsylvania: Becher (1973), Lloyd and Growitz (1977), Poth (1973), Wood (1980), and Sloto and Davis (1983).

## Physical Features

The Piedmont Province of Virginia is characterized by gently rolling hills and long northeast-southwest trending ridges. Elevations range from about 200 feet above sea level in the east to 1,000 feet above sea level along the western boundary. Local relief between highland areas and valley floors may exceed 100 feet.

An intricate network of rivers and streams dissects the Piedmont Province. While most of the drainage system follows a dendritic drainage pattern, some stream reaches follow nearly straight courses called lineaments. These linear features are controlled by fracture systems in the underlying bedrock. The significance of lineaments in the development of ground-water supplies is discussed later in this report. Major rivers crossing the Piedmont include the Potomac, Rappahannock, James, Appomattox, Nottoway, Meherrin, Roanoke, and Dan Rivers. Major lakes include Lake Anna and the John Kerr Reservoir.

## Climate

The climate of the Piedmont is mild and humid with an average annual temperature of about 56°F. Temperatures are generally lowest in January and highest in July. The distribution of average annual precipitation over Virginia is shown in figure 2. The Piedmont, as shown in the figure, receives an average annual precipitation of about 44 inches. A bar graph showing average monthly precipitation in the Piedmont Province at Danville, Virginia, is provided in figure 3. Although rather evenly distributed throughout the year, average monthly precipitation usually increases in late spring and summer and decreases in the fall (LeGrand, 1960).

## Geology

Bordered on the west by the Blue Ridge Province and on the east by the Coastal Plain Province, the Piedmont Province consists primarily of metamorphic rock containing igneous intrusions of varying size. The major rocks include schist, gneiss, marble, slate, and quartzite, all of which may be

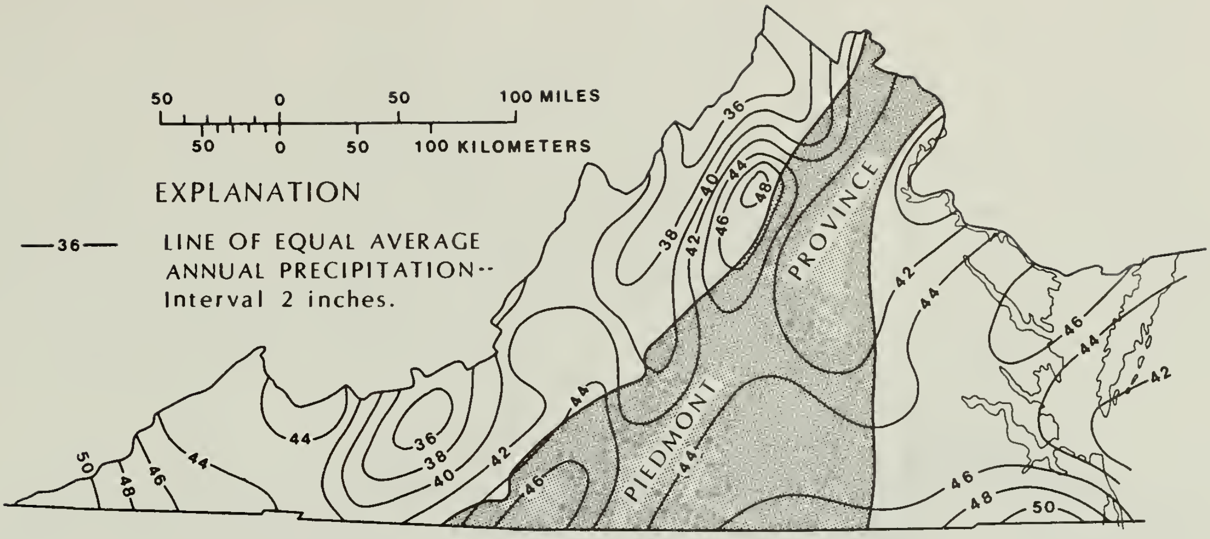


Figure 2.-- Average annual precipitation in Virginia (U.S. Geological Survey, 1979).


Figure 3 -- Average monthly precipitation in Danville, Virginia, Piedmont Province (Le Grand, 1960).

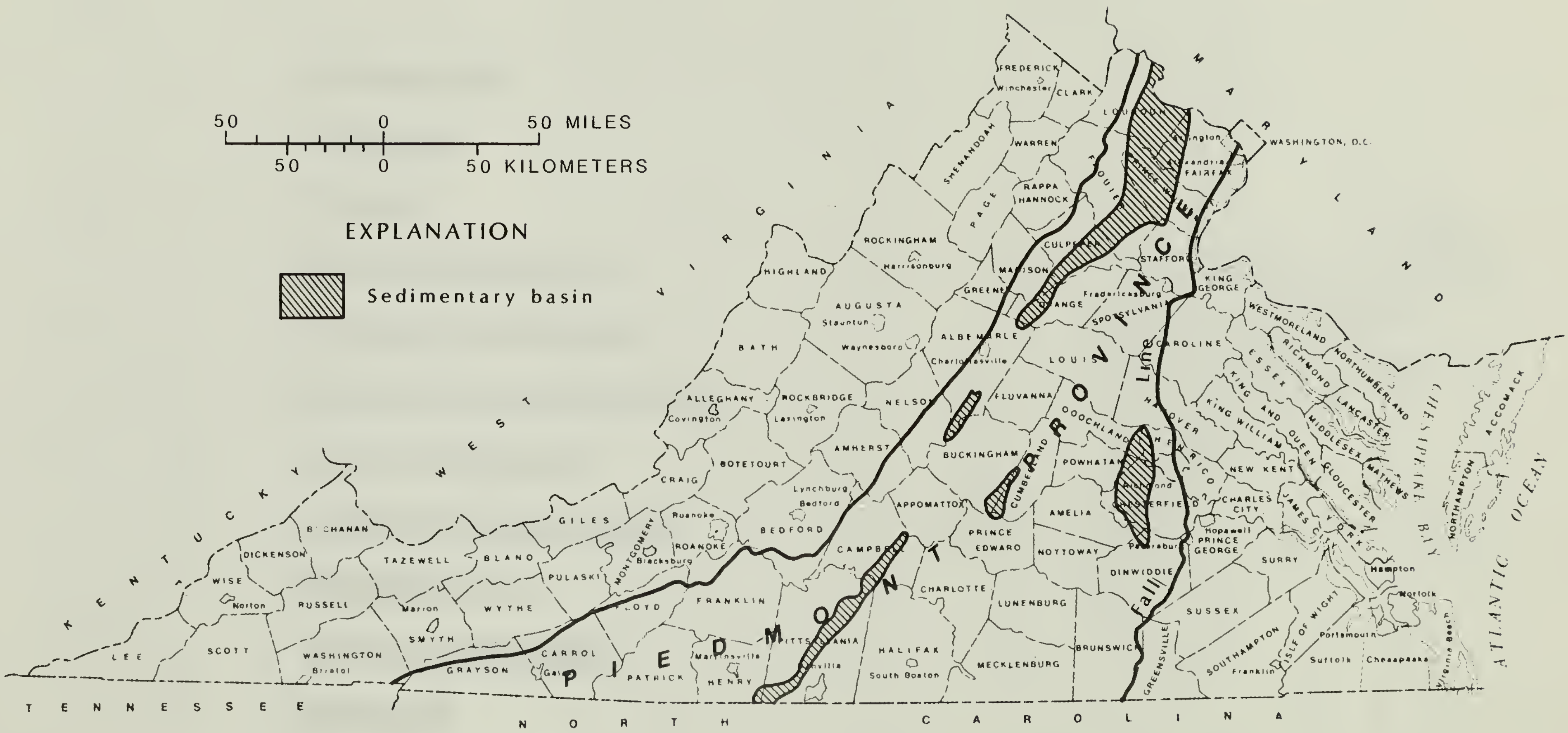


Figure 4.-- Sedimentary basins in the Piedmont Province of Virginia.

intruded by granite and diabase. Five sedimentary basins intruded by diabase sills and dikes are located in the Piedmont (fig. 4). Rocks in these basins include sandstone, siltstone, shale, conglomerate, and coal. Bedrock throughout the Piedmont is overlain by a nearly continuous layer of loose, weathered material. Referred to as "regolith," this material is composed of soil, saprolite (well-weathered rock), and alluvium (deposited by streams). The thickness of the regolith exceeds 100 feet in some areas of the Piedmont (Richardson, 1982). The geologic structure trends northeast-southwest, generally paralleling the Fall Line (border between the Piedmont and Coastal Plain Provinces) extending northeast into Maryland, Pennsylvania, and New Jersey and southwest into North Carolina, South Carolina, and Georgia. While rock formation names vary from state to state, rock composition and structure are similar throughout the Piedmont.

## AVAILABILITY OF GROUND WATER

Knowledge of the availability of ground water is important to the population of the Piedmont if the resource is to be utilized and managed effectively. This section addresses the availability of ground water by discussing the hydrologic cycle, water budget, occurrence and movement of ground water, factors affecting well yields, types of wells, and springs.

### Hydrologic Cycle

The hydrologic cycle is a global system of water and energy transfer powered by insolation from the sun. The oceans serve as the main energy collector and source of the two major elements in the hydrologic cycle -- water and heat energy. Latent heat of evaporation released during condensation serves to drive winds that scatter precipitation across the continents. All water falling on the continents eventually returns to the ocean to receive more solar energy and continue the cycle.

Precipitation falling on the Piedmont Province (fig. 3) is the only significant source of water to the Piedmont other than surface water in streams passing through from other geologic provinces. The hydrologic cycle as it functions in the Piedmont Province is illustrated in figure 5. Precipitation reaching the land surface either runs off into streams which make their way back to the oceans, or infiltrates the ground to pass through a more complicated, circuitous route to the sea. It is water following this more tortuous route through the ground that supplies the basic need for water to much of the flora and fauna (including man) of the Piedmont.

Water infiltrating the surface of the ground moves through the soil zone under the force of gravity downward until it reaches impermeable rock. On the way through the soil and underlying saprolite, some water remains lodged between the mineral grains and is available to the roots of plants in the unsaturated zone (zone of aeration). Much of this water, known as soil moisture or capillary water, is eventually returned to the air through evapotranspiration. Water passing down to the impermeable rock saturates the materials immediately above the rock and the fractures present within the rock. The upper surface of this saturated zone (zone of saturation) is referred to as the water table. Water below the water table may replace the soil moisture lost through evapotranspiration by moving up through the unsaturated zone by capillary movement. Water in the saturated zone below the water table can also be removed by constructing a well penetrating below the water table and installing a device such as a pump or bucket to lift the water to the land's

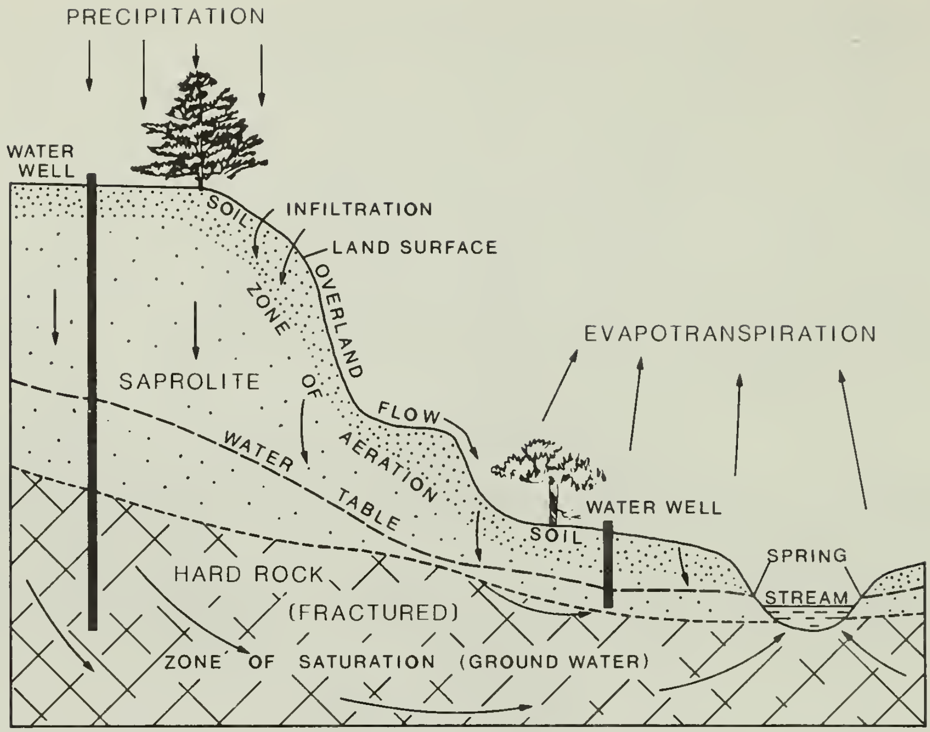


Figure 5.-- Water cycle in the Piedmont Province.
(Modified from Richardson, 1982.)

surface. In addition, water is lost from the saturated zone by ground-water flow where the water table reaches the surface, such as in streambeds, in valley bottoms, or in springs on hillsides. Loss of water from the zone of saturation by any means reduces the thickness of the saturated zone and lowers the altitude of the water table.

Over a period of years the system of ground-water gain through precipitation (recharge) is in balance with ground-water loss (discharge). In the short term, however, periods of less than normal precipitation can lower the water table, causing wells and springs to go dry, and dramatically reduce stream flow. Periods of greater than normal precipitation raise the water table, increase the depth of water in wells, and increase flow in springs and streams. Increases in the amount of water stored in the water table (storage) are, however, only temporary since the increase in storage is accompanied by increases in discharge.

The long-range relation between precipitation (recharge) and the altitude of the water table in a well in Louisa County in the Virginia Piedmont is shown in figure 6. The relation between precipitation and water levels over one year (fig. 7) demonstrates fluctuations in water levels throughout the year. There is a lag in time between periods of rain and periods of rise in the water table due to the time required for the soil to become saturated and allow water to pass down to the zone of saturation. A notable decline in the altitude of the water table occurs during the summer months due to the great increase in loss by evapotranspiration during the growing season. This decline in the water table takes place even though rainfall may be heavy during the same time period. Note in figure 6 that during the drought of 1980 and 1981, the lack of adequate precipitation prevented the normal rise in water level.

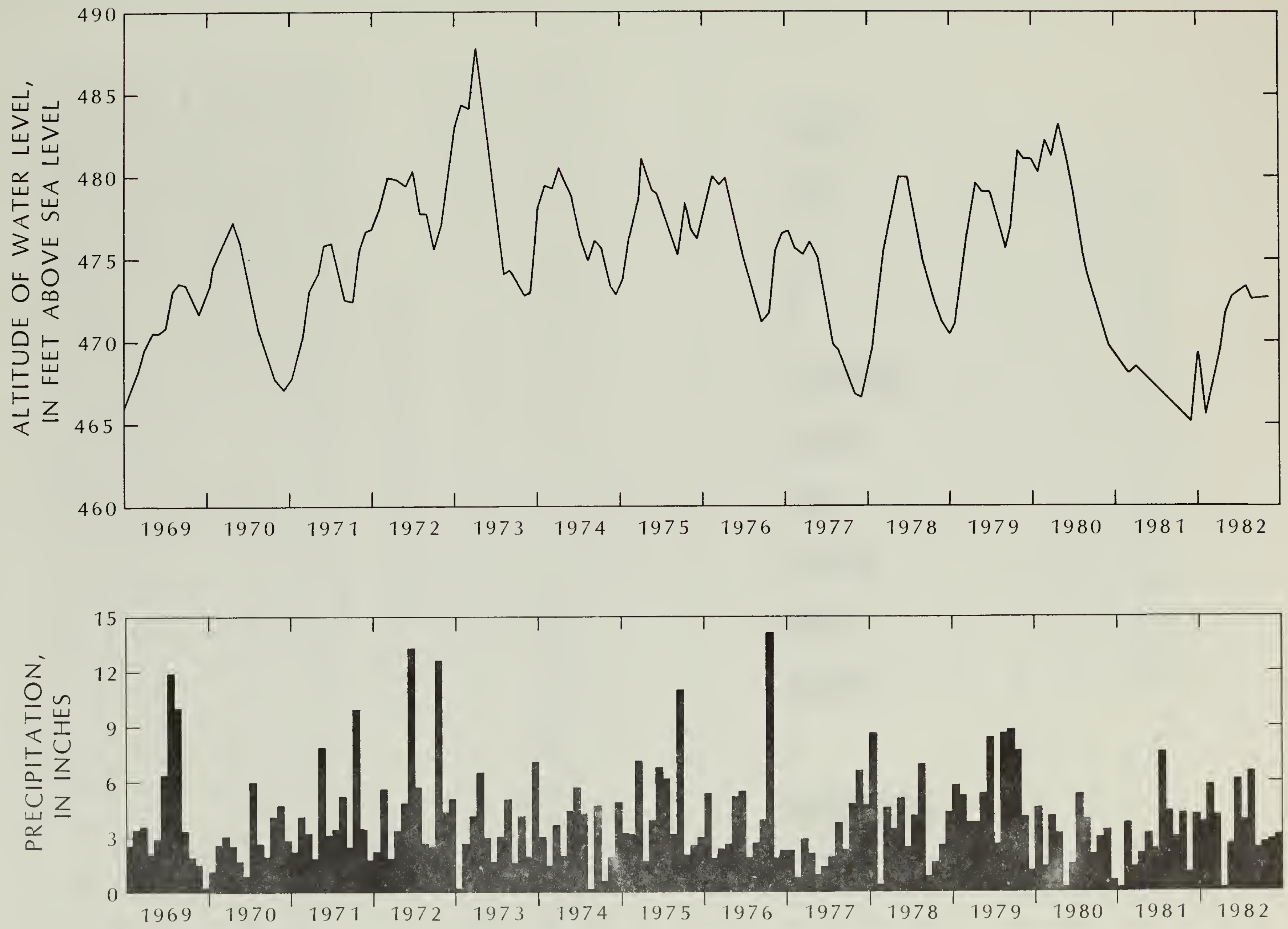


Figure 6.-- Hydrograph for observation well and precipitation record for weather station in Louisa County, Virginia, 1969-1982.

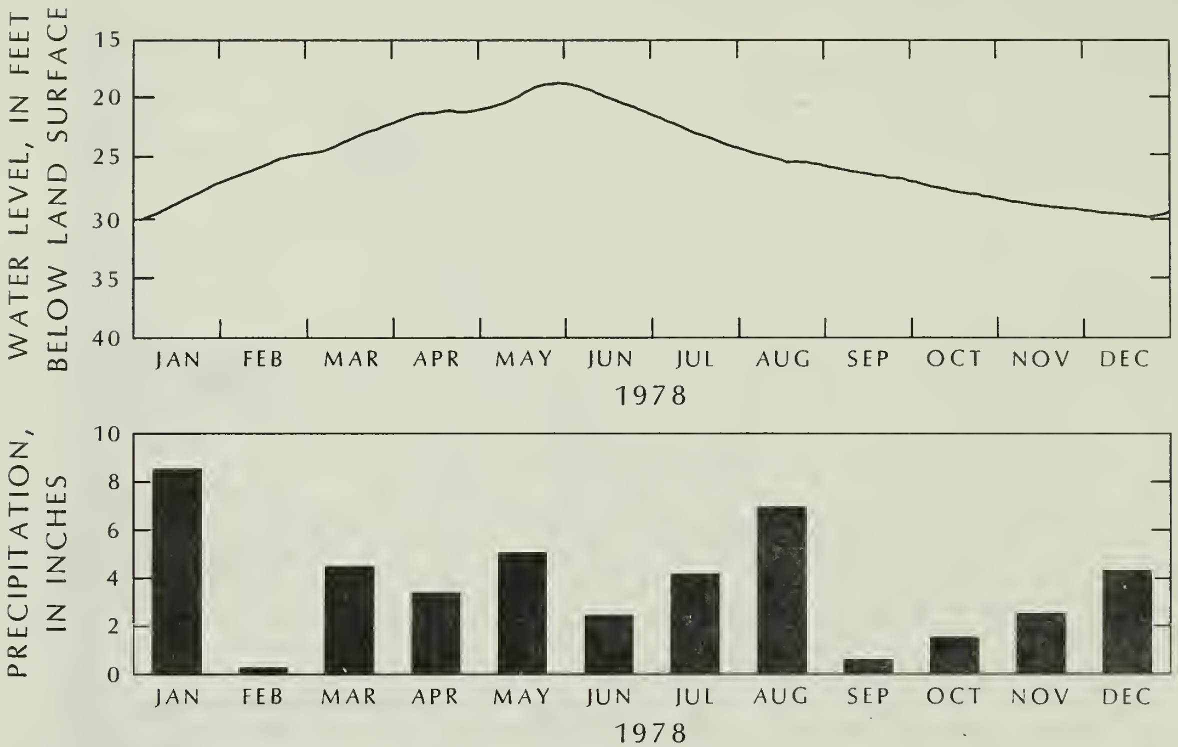


Figure 7.-- Hydrograph for observation well and graph showing precipitation in Louisa County, Virginia, 1978.

## Water Budget

The movement of water within the Piedmont can be expressed quantitatively by the hydrologic budget equation:

$$P = R + ET + \Delta S,$$

where:

$P$ = precipitation,
$R$ = runoff,
$ET$ = evapotranspiration, and
$\Delta S$ = change in ground-water storage

Precipitation and runoff (water appearing in streams) are easily measured and the change in ground-water storage over a long period of time can be considered equal to zero. Evapotranspiration then equals the difference between precipitation and runoff. This is true in the Piedmont because precipitation is the only source of ground-water recharge and water is not gained from or lost to deeper regional ground-water flow systems like those found in other areas of Virginia. If withdrawals are mad from the saturated zone by man, this must be totaled and entered into the right side of the equation as a positive term. Studies by Dingman and Meyer (1954) and Dingman and Ferguson (1956) in the Piedmont of Maryland and Washington, D. C. indicate that if there is no change in storage over a long period of time, about 70 percent of precipitation is lost from the basin through evapotranspiration and the remaining 30 percent is lost from the basin as runoff. Approximately 7 percent is surface-water runoff and approximately 23 percent is ground-water discharging into streams.

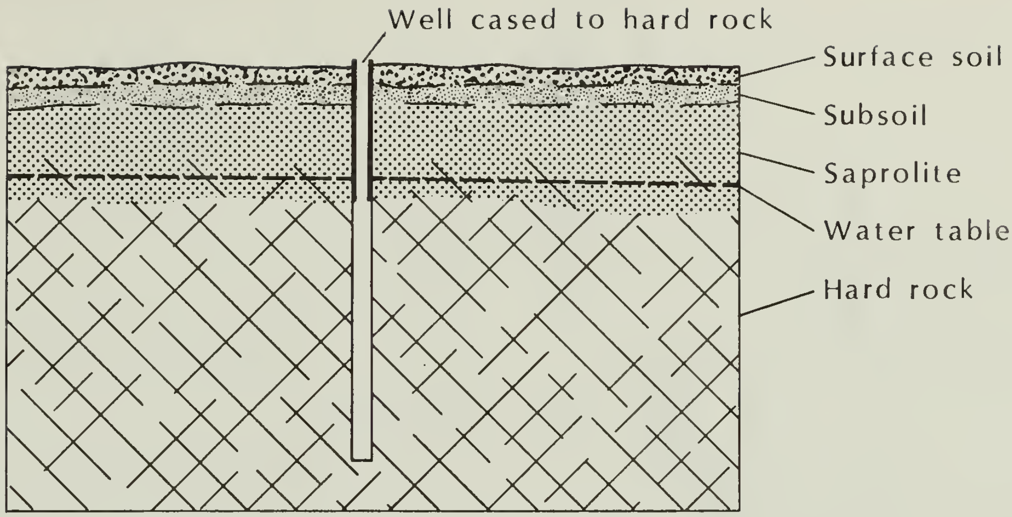


Figure 8.-- Typical subsurface cross section showing the character of materials penetrated by a well in crystalline terrane. (LeGrand, 1960.)

The areas studied receive about 44 inches of rainfall per year (consistent with Virginia Piedmont, see figure 3) indicating about 10 inches of precipitation per year recharge the water table. This water that is not lost through evapotranspiration and actually reaches the water table is referred to as effective recharge. Estimates of effective recharge in the Maryland Piedmont range from 8.5 to 11.3 inches and range from 20 to 27 percent of precipitation received (table 3).

## Occurrence and Movement of Ground Water

Water in the crystalline intrusives and metamorphic rocks of the Piedmont is found in fractures within the rocks as well as within the small spaces left in the saprolite by weathering processes (secondary permeability) (fig. 8). Little if any water moves among the mineral grains in the unweathered bedrock (primary permeability). In the sedimentary rocks of the Piedmont water moves through spaces among the particles within the rock as well as along fractures and bedding planes (fig. 9).

The percentage of rock volume that is open space available for water to occupy is referred to as porosity. Rocks with higher porosities have greater potential for storing water. A measure of the ease with which water moves through a rock is referred to as permeability. Larger connections allow more rapid movement between voids. If the openings within a rock are not intercon-

Table 3.--Summary of estimates of effective ground-water recharge in the Maryland Piedmont Province (from Richardson, 1982).

| Drainage basin | Period of record | Annual precipitation (inches) | Area of drainage basin ($mi^2$) | Effective ground-water recharge: Amount (inches) | Effective ground-water recharge: Percent of precipitation | Reference |
|---|---|---|---|---|---|---|
| Rock Creek | 1933-49 | 43.5 | 62 | 8.5 | 20 | Dingman and Meyer, 1954 |
| Little Gunpowder Falls | 1927-49 | 42.6 | 36 | 11.3 | 27 | Dingman and Ferguson, 1956 |
| Bennett Creek | [1]1976 | 42 | 62.8 | 11 | 27 | Otton, E.G., 1981 |
| South Branch of the Patapsco River | ([2]) | 43 | ---- | 10 | 23 | Do. |
| Do | ([2]) | 43 | ---- | 11 | 25 | Do. |
| Median values, all basins | ---- | 43 | ---- | 11 | 25 | |

[1]Analysis based on flow data for 1976 water year.
[2]Method is based on use of water levels in wells and not on streamflow data (Ferris and others, 1962, p. 131).

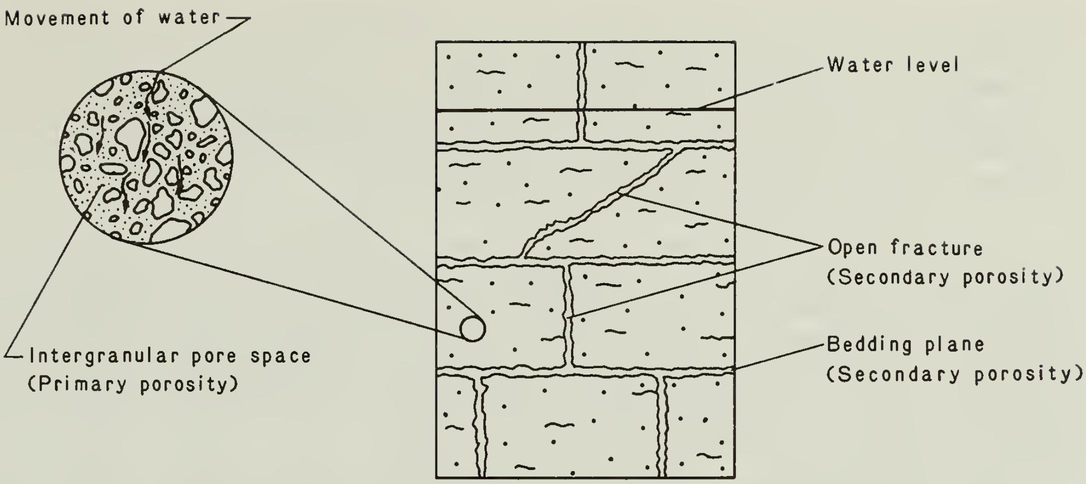


Figure 9.-- Primary and secondary porosity (modified from Wyrick and Borchers, 1981).

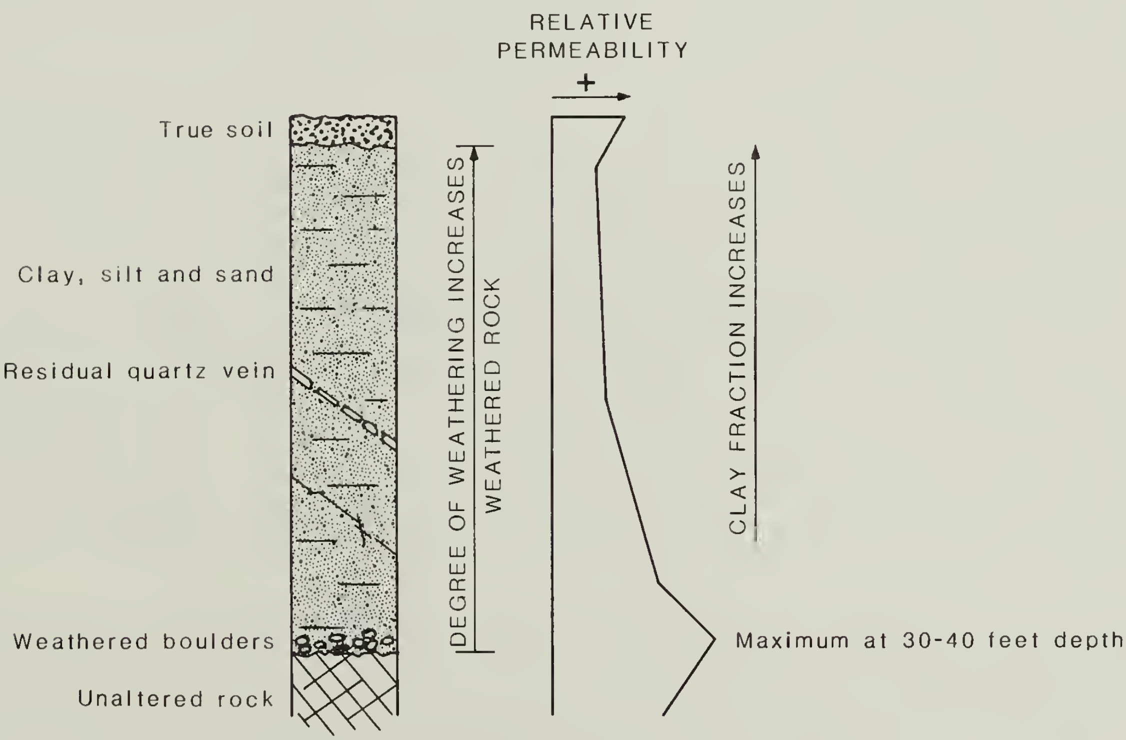


Figure 10.-- Idealized weathering profile showing fresh crystalline rock grading upward into true soil. (From Nutter and Otton, 1969.)

nected a rock will not be permeable no matter how high the porosity. Clay is an example of a material that has high porosity but low permeability due to the small size of the pore spaces. Clay is a weathering product of feldspar, an abundant mineral within rocks of the Virginia Piedmont, and its effect on permeability is shown in figure 10. Sandstone is an example of a rock that can have high porosity and high permeability.

Permeability is defined as the flow of water in gallons per day through a one square foot section of material (aquifer) under a gradient of one foot change in altitude of the water level per one foot horizontal distance. Laboratory analyses of samples of saprolite overlying crystalline rocks of the Maryland and Georgia Piedmont indicate permeabilities ranging from .01 gallons/day/foot$^2$ (about .0013 ft/day) to 115 gallons/day/ft$^2$ (about 15.4 ft/day) (Nutter and Otton, 1969).

In crystalline rock, wells must intercept fractures or zones of fracturing in order to be productive. Water is also available in the saprolite (weathered rock) down to solid bedrock, but concern over contamination of this most productive water-yielding zone by materials on the land's surface is resulting in laws that require this shallow zone to be sealed off during well construction. A well penetrating the fractured crystalline rock is illustrated in figure 11. Well casing seals off the weathered zone and water is derived exclusively from fractures. A well penetrating consolidated layered rock of a Piedmont sedimentary basin is shown in figure 12. The weathered zone is sealed off by well casing and water enters the well from spaces between rock particles, from bedding planes, and from fractures perpendicular to the bedding planes.

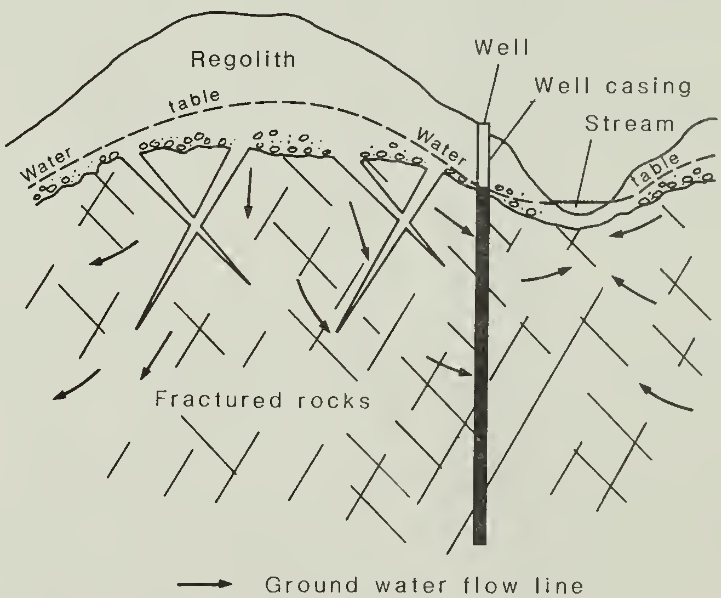


Figure 11.-- Diagram of ground-water occurrence in crystalline rocks (modified from Otton, 1981).

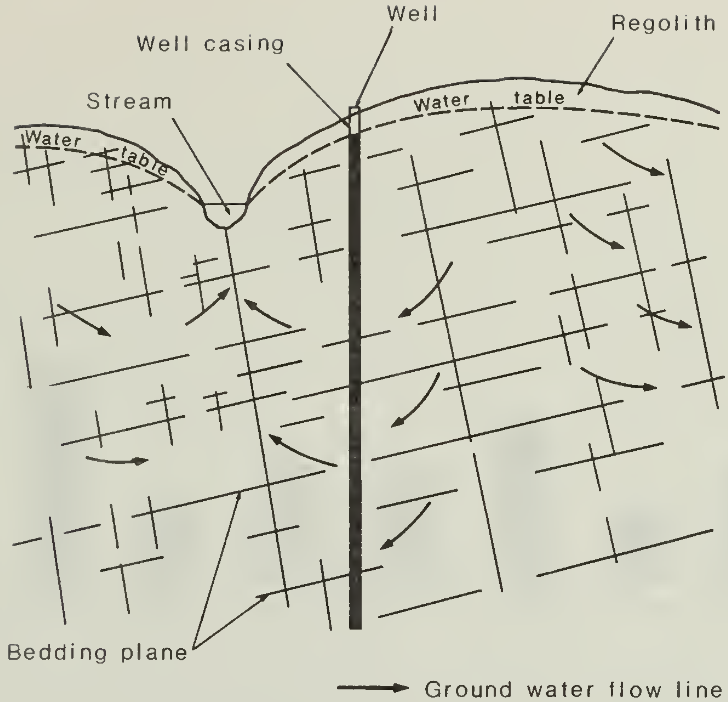


Figure 12.-- Diagram of ground-water occurrence in consolidated sedimentary rocks (modified from Otton, 1981).

## Factors Affecting Well Yields

The abundance of fractures in the rock aquifer is one of the most important factors affecting the amount of water a well yields. Because fractures act as conduits for the movement of water, the greater number of fractures penetrated the greater is the yield. Nutter and Otton (1969) state "it appears that in many areas underlain by crystalline rocks the average spacing of joints is 10-20 feet." There is however a limiting depth where the weight of overlying rock tends to seal fractures and few wells are drilled deeper than 300 ft. While supply to a well in crystalline rock is not likely to be increased by drilling deeper than about 300 feet, yields of wells in sedimentary rocks increase with deeper drilling. The relation between well yields and well depth in the layered rock of a sedimentary basin in Maryland is shown in figure 13. Well yields increase with depth. The relation between well depth and number of joints encountered in the sedimentary basin is shown in figure 14. The greatest number of fractures are encountered in the upper 200 feet.

Fracturing in rocks promotes weathering, and as a result valleys are located in the areas of greatest fracture concentrations. Surface drainage patterns in the crystalline rock of Baltimore County in the Maryland Piedmont show lineations and preferred azimuths supporting the idea that valley and stream locations are probably controlled by fractures (fig. 15).

Nutter and Otton (1969) found that valley wells have three to four times the yield at less than 90 percent the depth of hilltop wells. As well as having more conduits to convey water to the well, valley wells are likely to have less drawdown per volume of water withdrawn (greater specific capacity) than are hilltop wells because fractures in the valley provide greater capacity for ground-water storage and water flows toward valleys and away from hilltops (fig. 5).

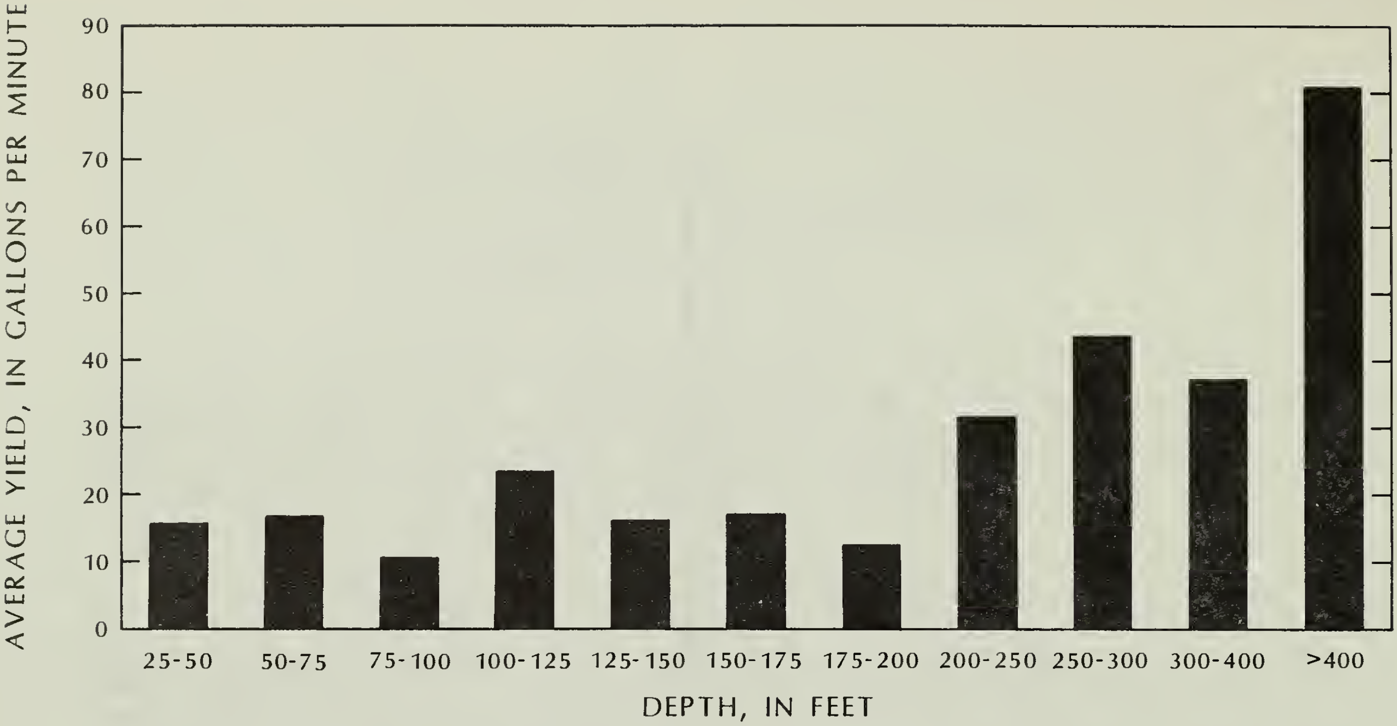


Figure 13.-- Relation between well depth and average yield of sedimentary rocks in the Maryland Piedmont (modified from Nutter, 1975).

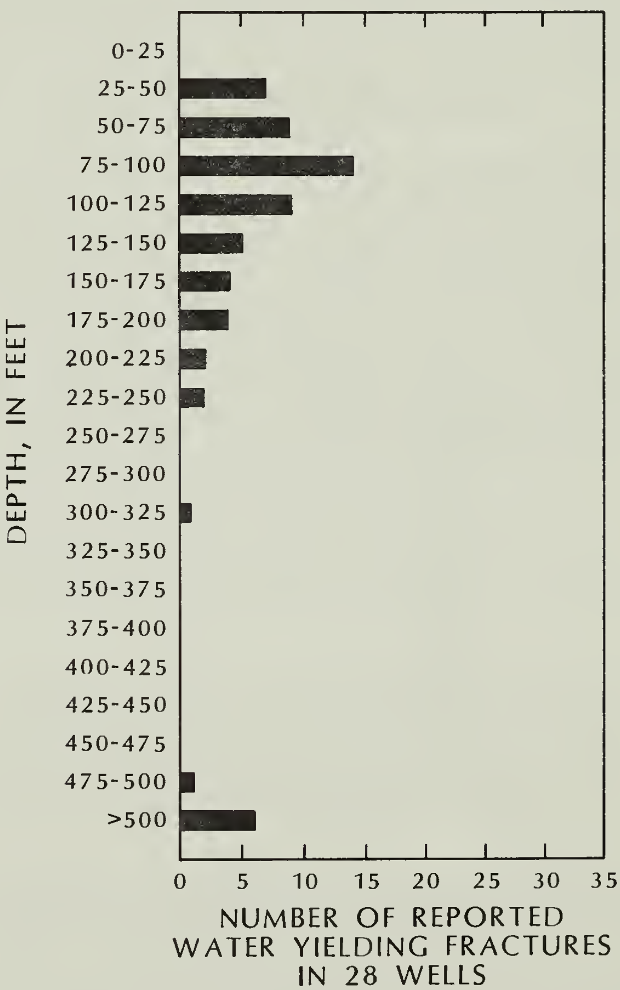


Figure 14.-- Number of water-yielding fractures in wells within a Maryland sedimentary basin (modified from Otton, 1981).

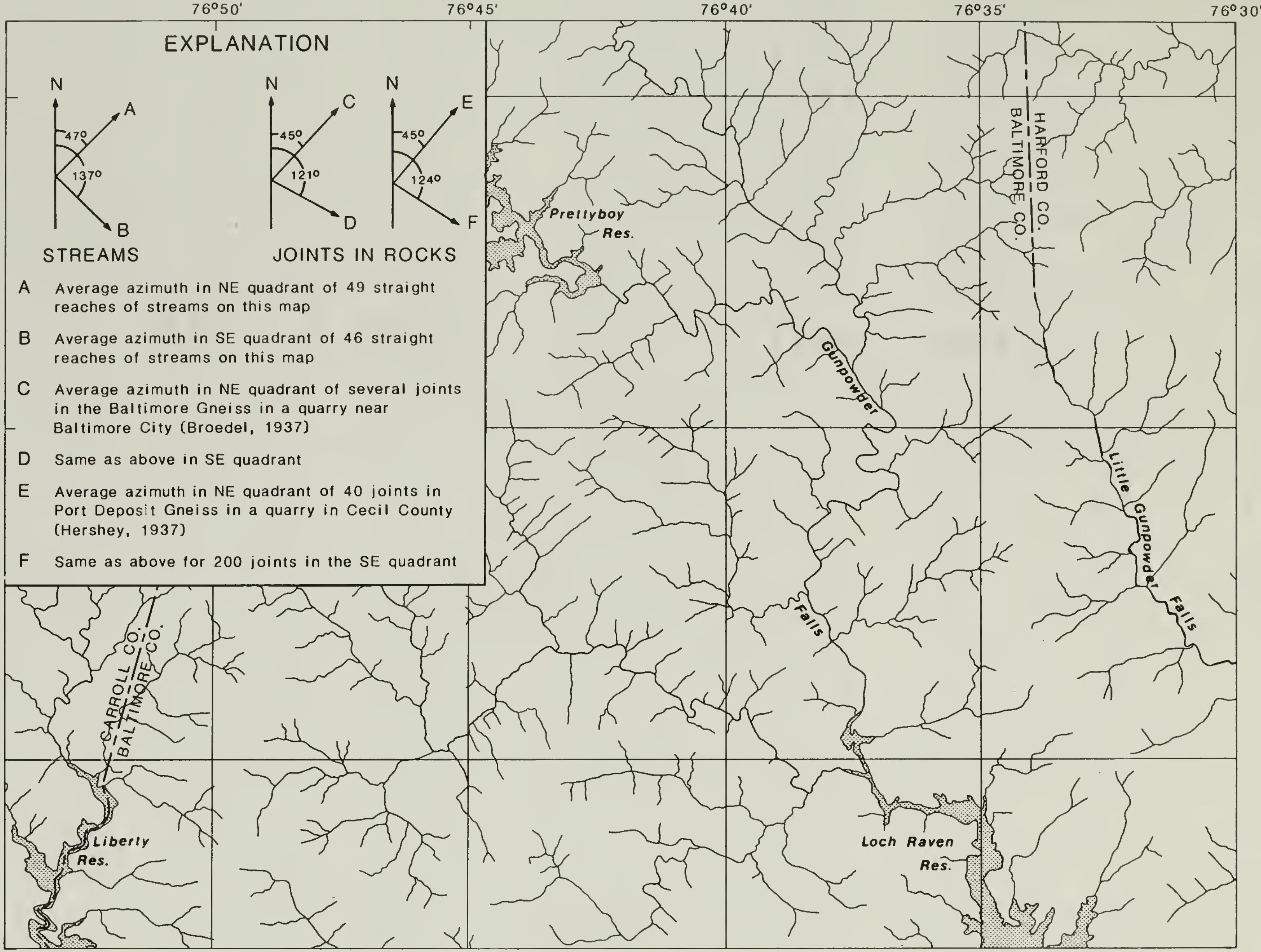


Figure 15.-- Drainage pattern in a part of the Maryland Piedmont and average azimuth of stream reaches and joints in rocks (Nutter and Otton, 1969).

LeGrand (1960) studied the difference in well yield in different topographic locations in the southern Piedmont of Virginia (table 4); however, LeGrand's study does not include valley wells. A "flat" is a "broad upland area without long, steep slopes nearby." A "draw" is a "slight to moderate depression leading downward to a stream valley and upward to a saddle in a ridge or gap between two hills." Yield from valley wells would presumably exceed those of either flats or hills. A comparison of well yield and topographic setting in Harford County, Maryland was made by Nutter (1977) (fig. 16) showing that valley and draw wells are by far the most productive. The same relation between topographic location and well yield found in the crystalline rocks can be seen in the sedimentary rocks. The relation between topographic location and well yields in sedimentary rocks of the Maryland Piedmont is shown in figure 17. Wells located in valleys have significantly higher yields than wells located on slopes and hilltops. In Harford County, Maryland, Nutter (1977) found higher yields in wells located near fault zones. Fault zones, due to movement of the rock, are characterized by an abundance of fractures in rock.

Rock type is another variable affecting well yields. Because primary porosity (volume of intragranular spaces) is low or non-existent in all the crystalline metamorphic rocks, secondary porosity (fractures) controls the amount and movement of ground water within the rocks. In the clastic rocks of the sedimentary basin, primary porosity can provide potential for making wells more productive than wells located in crystalline metamorphic rocks (Nutter and Otton, 1969). LeGrand (1960) and Nutter and Otton (1969) compare well yields in different rock types in Pittsylvania County, Virginia (table 5) and in Maryland (table 6). Neither paper lists an average yield greater than 17 gallons per minute. Averages from Nutter and Otton (1969) tend to be lower and may be more realistic because of a greater number of wells studied. The data suggest that no one crystalline rock type is a more outstanding water producer (aquifer) than the others.

## Types of Wells

Wells are man-made excavations into the saturated zone to obtain a water supply. Three well types are prevalent in the Piedmont: (1) dug, (2) bored, and (3) drilled. Water in a well is removed by using a device such as a bucket or pump to lift the water to the surface.

Dug wells are large diameter wells, frequently exceeding 30 inches, completed in the regolith to a depth just below the water table (fig. 5). Excavation is generally accomplished with a shovel and a bucket (to lift earth material to surface). Stone, brick or wood are common materials used to line the walls of the hole to prevent collapse. Particularly susceptible to water-table fluctuations because they intercept a small interval of the saturated zone, dug wells often dry up during drought periods.

Bored wells, similar to dug wells, are also excavated into the regolith. Usually completed to a greater depth (frequently to bedrock) than dug wells, bored wells intercept a larger interval of the saturated zone and provide a more dependable supply of water. Bored wells, commonly 18 or 24 inches in diameter, are installed by mechanically driven augers. An auger is a bucket-like device with a cutting edge on the bottom. Earth material is brought to the surface after each interval of hole is completed. Concrete casing is installed in the hole to prevent collapse and, when properly grouted, to protect the well from surface contamination. In areas where the saturated regolith is thick, bored wells are successful in all but exceptionally dry periods.

Table 4.—Average yield of drilled wells according to topographic location in Halifax and Pittsylvania Counties, Virginia. (LeGrand, 1960).

| Topographic Location | Number of wells | Average depth (feet) | Yield (gallons per minute) | | Percentage of Wells Yielding | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Average | Per foot of well | Less than 5 gallons a minute | 5 to 10 gallons a minute | More than 10 gallons a minute | More than 20 gallons a minute |
| Hill crest | 172 | 160 | 7 | .05 | 39 | 45 | 16 | 9 |
| Slope | 82 | 151 | 20 | .11 | 9 | 33 | 58 | 44 |
| Flat | 7 | 163 | 23 | .14 | 0 | 14 | 86 | 70 |
| Draw | 21 | 140 | 42 | .29 | 0 | 9 | 91 | 81 |
| All wells | 282 | 156 | 14 | .09 | 26 | 38 | 36 | 26 |

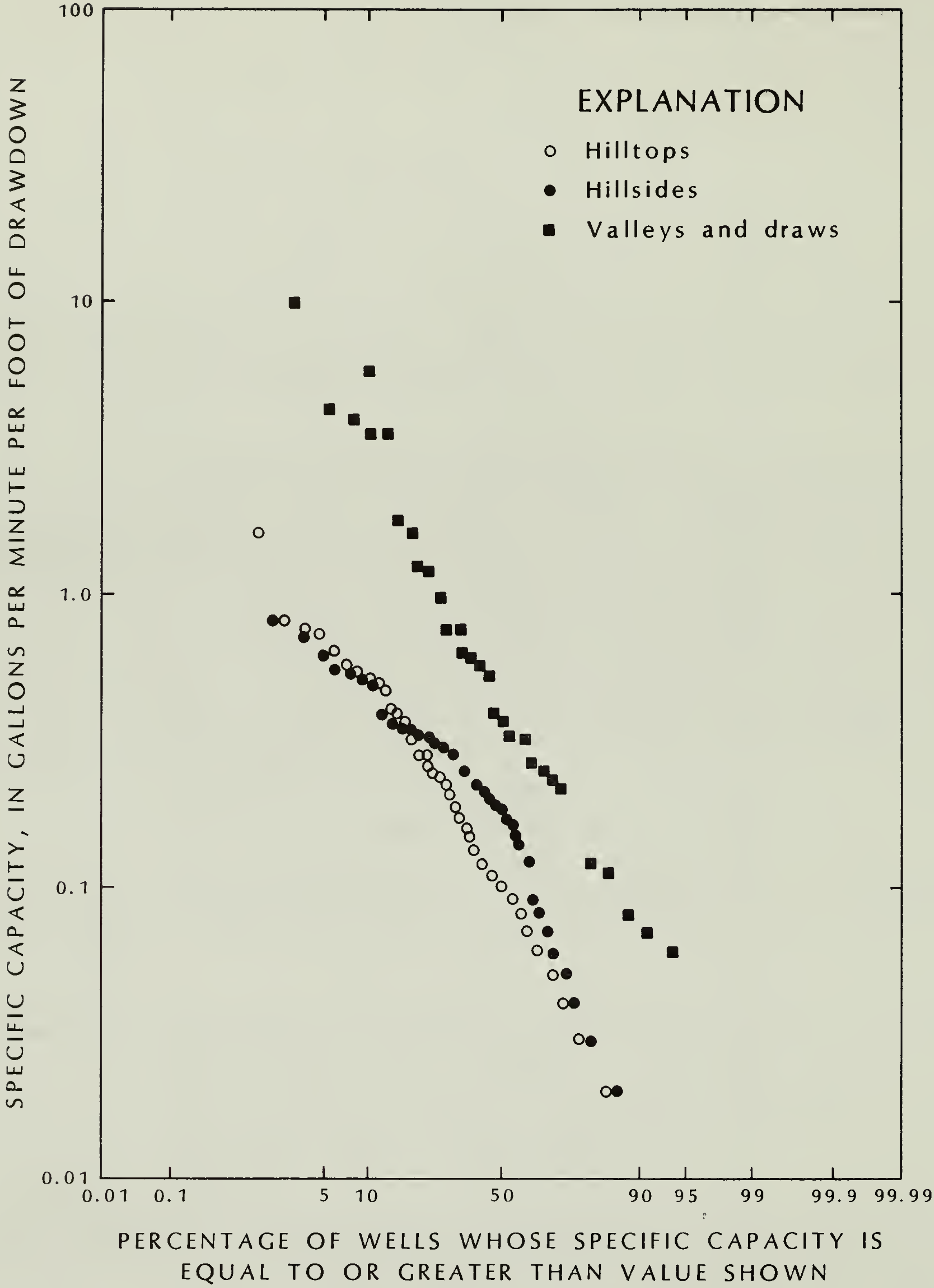


Figure 16.-- Relation between yield of wells in valleys and draws, on hillsides and on hilltops in the Maryland Piedmont (Nutter, 1977).

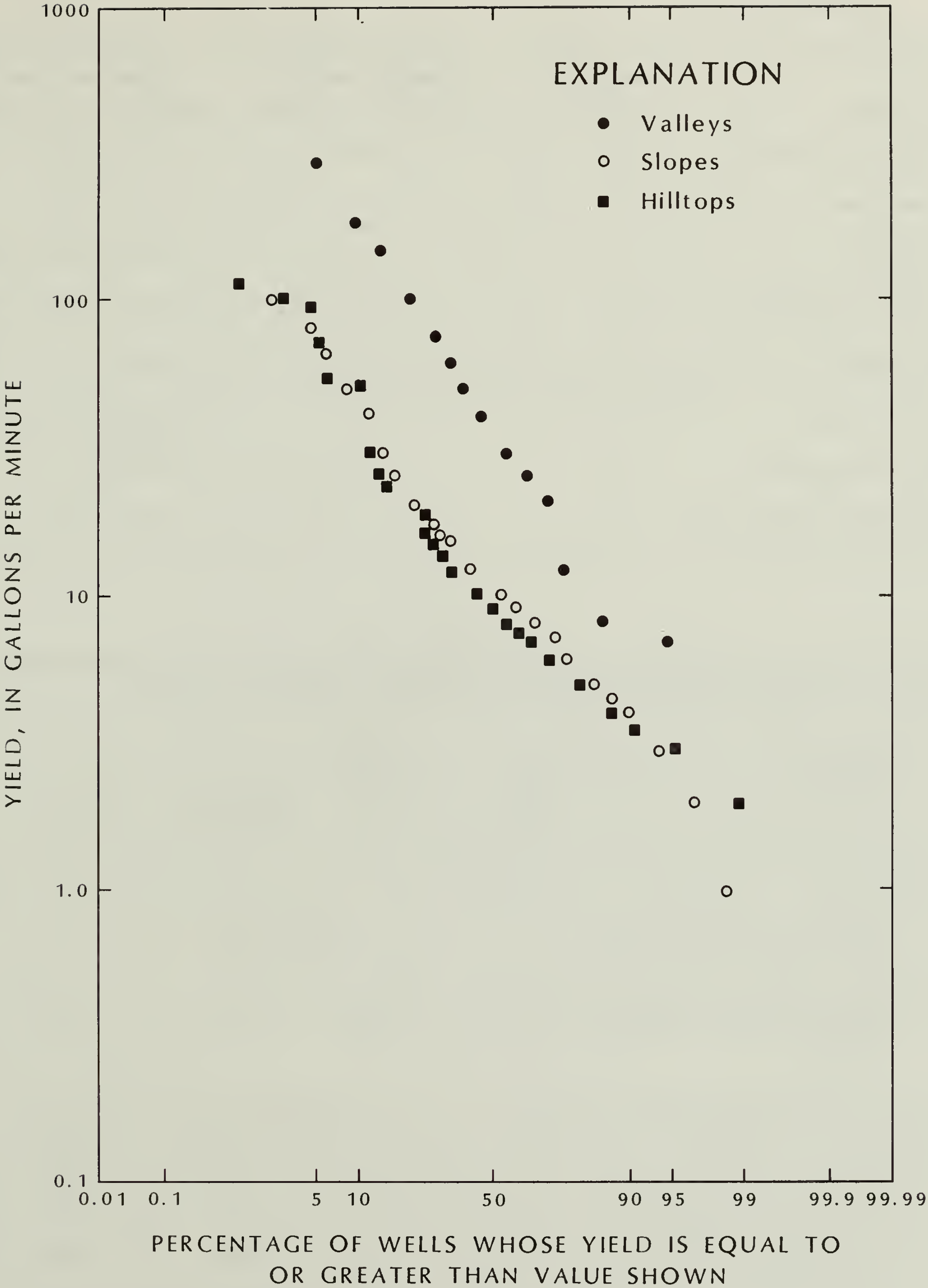


Figure 17.-- Topographic influence on the yield of wells in the sedimentary rock aquifers of the Maryland Piedmont (modified from Nutter, 1975).

Table 5.--Average yield of drilled wells according to rock type in Virginia Piedmont (LeGrand, 1960).

| Rock Type | Number of wells | Average yield (gallons a minute) | Range in yield (gallons per minute) |
|---|---|---|---|
| Shale and sandstone | 20 | 11 | 1/2 to 60 |
| Mixed gneisses | 172 | 17 | 1/8 to 220 |
| Mica schist | 34 | 11 | 1/2 to 30 or more |
| Mica schist and granite | 20 | 13 | 2 1/2 to 30 or more |
| Granite gneiss | 26 | 14 | 1 to 150 |
| Hornblende gneiss | 8 | 14 | 4 to 50 |
| Virgilina greenstone | 14 | 8 | 1 to 25 |
| Sericite schist and slate | 15 | 7 | 1/4 to 20 |

Table 6.--Statistical data relating well yields to rock type of Proterozoic age in Maryland (modified from Nutter and Otton, 1969).

| Formation or rock unit | Mean yield (gmp) | Median yield (gpm) | Standard deviation | No. of wells |
|---|---|---|---|---|
| Cockeysville Marble | 11.9 | 10 | 10.2 | 159 |
| Wissahickon Formation (metagraywacke facies) | 11.1 | 10 | 8.5 | 81 |
| Wissahickon Formation (upper pelitic schist facies) | 11.0 | 10 | 8.1 | 242 |
| Baltimore Gneiss and Setters Formation | 8.6 | 8 | 6.9 | 174 |
| Gabbro and serpentine | 7.8 | 6 | 6.4 | 278 |
| Wissahickon Formation (lower pelitic schist facies) | 7.8 | 5 | 5.0 | 208 |
| All formations | 9.4 | -- | -- | 1142 |

Drilled wells, penetrating the fractured bedrock beneath the regolith, afford the largest, most dependable supply of water. Drilling is accomplished with a rotating bit that is attached to a series of long steel rods which extend up to the land surface. A diesel-powered drilling rig on the land surface rotates, raises, and lowers the rods and bit as the hole is excavated. Drilling fluid, usually air, water or foaming agent, is used to bring the drill cuttings to the surface. Casing, constructed of steel or polyvinylchloride (PVC), is installed down to the top of bedrock. The casing prevents collapse of the regolith and, when properly grouted, prevents contamination by surface water and allows ground water to enter the well only through fractures in the uncased bedrock section of the wells. According to LeGrand (1960), pumps (usually electric submersible) are usually installed about 25 to 50 feet below the bedrock surface to maximize yields. Extensive fracture systems occurring in some locations enable drilled wells to tap water stored in a large volume of regolith. The larger yield and lower susceptibility to water-table fluctuations make drilled wells the most desirable well type in Virginia's Piedmont.

## Springs

Springs were an important source of water to early settlers of the Piedmont of Virginia. The location of springs frequently influenced the establishment of homes and villages. When located close to homes, springs offer two advantages over wells as sources of water: (1) much lower installation and maintenance costs and (2) little or no pumping costs. Springs used for water supply are covered by wood or masonry shelters (spring houses) to prevent surface contamination at the spring site. A shallow hole is excavated to provide storage for water withdrawal and to maximize discharge of ground water. Water supplied from springs located uphill from homes is delivered to the homes by gravity drainage. Water supplied from springs located downhill from homes is usually delivered by the use of a small electric pump.

Springs in the Piedmont of Virginia generally yield less than 10 gallons per minute. Factors affecting spring yields include thickness of regolith, position of water table with respect to the bedrock surface and fractures, and topographic setting.

Springs occur in locations where the regolith is thin or absent and the water table intersects the land surface. Ground water, released from storage in the regolith and transmitted through fractures in the bedrock, flows out of the fractures and along the surface of exposed bedrock. A substantial thickness of soil covered by vegetation will consume discharging ground water by evapotranspiration, preventing water from flowing freely to the land surface. Springs at the base of hills (especially in draws) provide the highest yields due to the large volume of regolith drained. Although most springs flow at a nearly steady rate throughout the year, springs in upland areas draining small volumes of regolith may flow only during wet periods when the water table is high enough to intersect the land surface.

## QUALITY OF GROUND WATER

The quality of ground water is affected primarily by the chemical composition of the regolith and bedrock through which the water moves. Natural factors contributing to ground-water quality are: mineral composition, seasonal variation in the amount of effective recharge, and duration of water-rock contact and mean annual air temperature. Contamination of ground water, a result of man's activities, also affects ground-water quality. Sources of ground-water contamination within the Piedmont include septic tank systems, sanitary landfills, sewage lagoons, petroleum spills, leaking pipelines, leaking gasoline storage tanks, improperly constructed water wells, certain agricultural activities (fertilizers, pesticides, feedlot and barnyard wastes), highway de-icing salts and infiltration of poor quality surface water from lakes and streams (Murphy, 1979).

The mineral composition of the regolith and bedrock strongly affects the quality of ground water passing through it. Ground water from most light-colored crystalline metamorphic and igneous rocks is generally soft ($\leq$60 mg/L hardness), slightly acidic (pH <7.0) and low in dissolved solids. Water moving through these silica-rich rocks picks up very little dissolved mineral constituents due to the chemically resistant nature of the silicate minerals. Water found in marble, which is also light-colored, is generally hard ($\geq$120 mg/L hardness), more highky mineralized, and basic (pH $\geq$7) because of the higher solubility of the carbonate minerals in the rock.

Ground water from the dark-colored crystalline metamorphic and igneous rock is generally harder, slightly more alkaline, and moderately higher in dissolved solids due to the higher solubility of the calcium-bearing and magnesium-bearing minerals in these rocks. Problems with iron and manganese are more common in dark-colored rocks due to the abundance of iron-bearing and manganese-bearing minerals in the rocks.

Ground water from sedimentary rocks is generally hard (hardness $\geq$120 mg/L) to very hard (hardness $\geq$180 mg/L), slightly alkaline, and high in dissolved solids. High concentrations of sulfate (>250 mg/L) are a common problem with deeper wells and directly correspond with high concentrations of dissolved solids. As in crystalline rocks, problems with iron and manganese occur. The relation between well depth in sedimentary rocks and dissolved solids can be seen in figure 18. Concentration of dissolved solids increases with well depth in siltstone that contains the minerals gypsum and pyrite, which are sources of dissolved sulfate.

Basic differences in water quality within the crystalline metamorphic terrane, characteristic of most of the Piedmont, and the sedimentary terrane characteristic of the sedimentary basins can be seen in the trilinear diagrams provided in figure 19. Water from crystalline rocks contains a balanced mixture of calcium, magnesium, and sodium ions (data points plot generally within the inner triangle of the cation triangle). Water from the sedimentary rocks tends to be enriched in calcium (data points plot generally out of the inner triangle and are displaced toward the 100 percent calcium end of the cation triangle). The greater amount of calcium is due to the presence of limestone and calcite cements in the rocks. Water from both the crystalline rocks and sedimentary rocks is rich in bicarbonate ion (data points plot generally near the 100 percent carbonate plus bicarbonate corner of the anion triangle). Water analyses from the crystalline rocks plot toward the chloride corner of the anion triangle while samples from the sedimentary rocks plot toward the

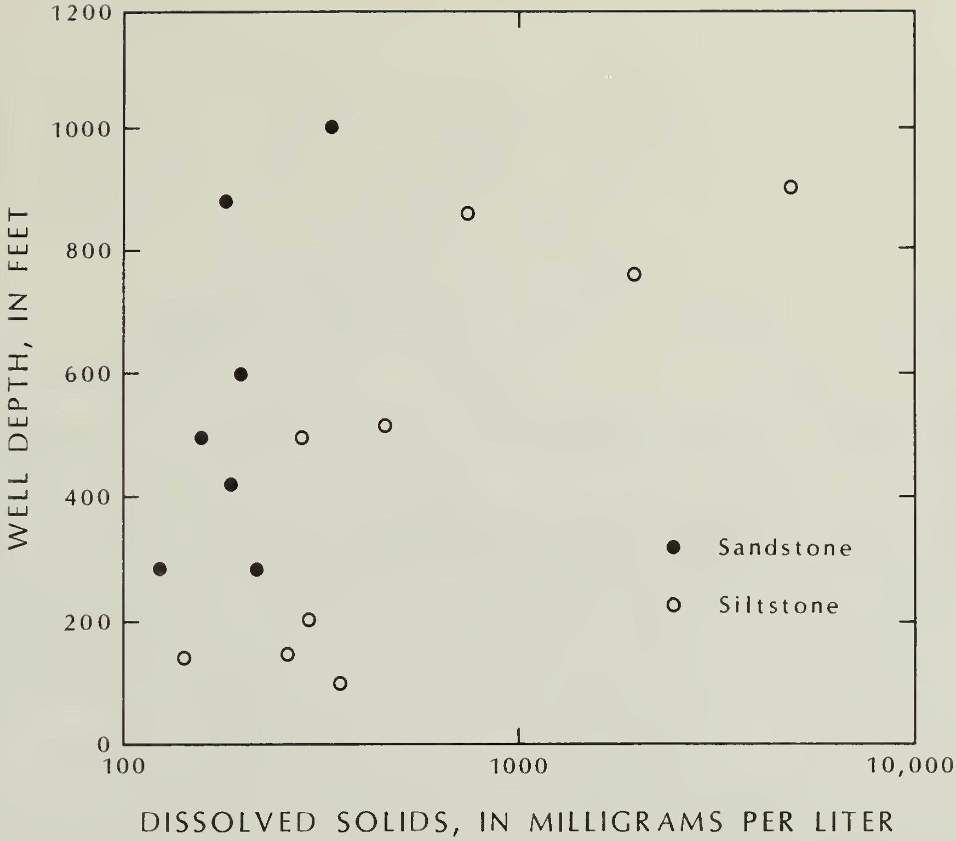


Figure 18.-- Relation between well depth and dissolved solids in sandstone and siltstone in sedimentary basin (Culpeper Basin) in Virginia.

sulfate corner of the anion triangle. Higher chloride content in crystalline rocks is probably a product of the igneous and metamorphic processes that formed the crystalline rocks while the sulfate content in the sedimentary rocks is probably a result of the weathering of the minerals pyrite and gypsum known to be present in the sedimentary rock.

Seasonal variation in the amount of effective recharge affects ground-water quality by controlling the amount of soluble constituents leached and carried into the ground-water system. Dissolved constituents from the surface and soil are derived from natural sources such as animal waste, humus, dead plant and animal matter, etc. and artificial sources such as fertilizers, pesticides, oils from streets, etc.

The duration of water-rock contact is one of the factors that determines the amounts of mineral constituents from the regolith and bedrock that dissolve into the ground water. The chemical processes responsible for the leaching of these constituents may require considerable time. Springs, frequently associated with relatively rapid ground-water movement at shallow depths, are generally low in dissolved mineral content due to the short period of water-rock contact.

Other aspects of ground-water quality that are of concern in the Piedmont of Virginia include: hardness, sulfate concentration, nitrate concentration, pH, and color.

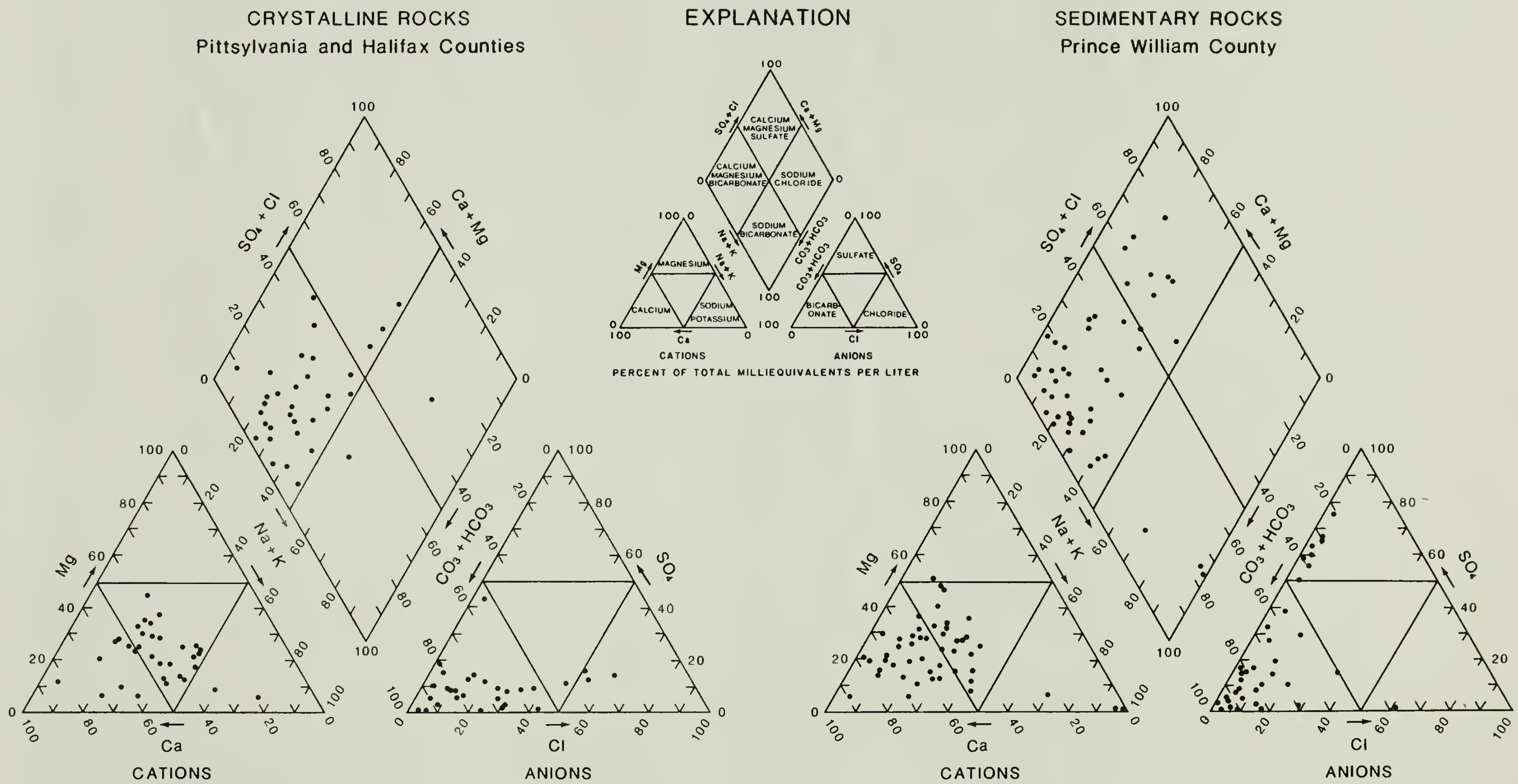


Figure 19.-- Water quality in crystalline terrane (Pittsylvania and Halifax Counties, Virginia) and sedimentary terrane (Prince William County, Virginia).

Hardness is a result of the presence of chemical constituents, usually calcium and magnesium, in water. Calcium and magnesium ions in hard water complex with the organic molecules in soap to form curds, so that much more soap is required for cleaning. Although there is no safe drinking water limit, Durfor and Becker (1964) use the following classification:

| | |
|---|---|
| 0-60 mg/L | soft |
| 61-120 mg/L | moderately hard |
| 121-180 mg/L | hard |
| more than 180 mg/L | very hard |

While ground water in the crystalline rocks of the Piedmont is generally soft, water from sedimentary rocks may be hard or very hard.

Sulfate ($SO_4$) in high concentrations (>250 mg/L) can have a laxative effect on user and can give a bitter taste to the water. Low concentrations are found in most ground water from crystalline metamorphic and igneous rocks because there are no abundant mineral sources. High concentrations are found in sedimentary basins because source minerals pyrite and gypsum are common. Unusually high concentrations may indicate contamination from man-made wastes.

Nitrate ($NO_3$) in low concentrations (0.1-1.0 mg/L) naturally occurs in ground water due to decay of organic matter in soils. Higher levels usually indicate contamination from fertilizer, animal waste, or septic tank effluent. High concentrations of nitrate can cause a condition known as methemoglobinemia or blue babies. The U.S. Environmental Protection Agency (1979) has set 10 mg/L as the acceptable limit for nitrate in drinking water.

pH is a scale ranging from 0-14 indicating whether a solution is acidic or alkaline:

<u>pH Value</u>

<7.0 - acidic
7.0 - neutral
>7.0 - alkaline

The presence of dissolved carbon dioxide ($CO_2$) from atmosphere and soil gases tend to lower the pH of ground water. Either highly acidic or highly alkaline ground water can corrode pipes and plumbing fixtures. Acidic water is a common and naturally occurring phenomenon within the Piedmont Province and can corrode copper water lines, resulting in dissolved copper and lead in drinking water.

Color is important for aesthetic reasons and often associated with staining problems. Color in ground water is often a result of iron or manganese in the water. Water from some metamorphic rocks may become dark colored as dissolved iron and manganese are exposed to oxygen. Staining of laundry and plumbing fixtures is usually related to significant iron and manganese concentrations. Some crystalline metamorphic rocks and sedimentary rocks may yield excessive dissolved iron (>.3 mg/L) and dissolved manganese (>.05 mg/L).

## Sources of Ground-Water Contamination

Septic tank systems, commonly used for sewage disposal in the rural Piedmont of Virginia, are the most widespread source of ground-water contamination in the Piedmont. Contaminants from septic tanks include nitrates, sulfates, chlorides, bacteria, and viruses. The ability of septic tank systems to dispose of sewage while preventing movement of potential contaminants into the ground-water system depends on proper placement of drainfields. The location of a drainfield, determined by a State or County health official, is based to some extent on the following criteria: (1) soil characteristics such as soil thickness, texture, mineral content, pH, bacteria content (for biodegradation of sewage) and filtering capacity, (2) adequate distance from site and streams, springs, (3) elevation of nearby wells, and (4) zoning regulations. After years of use, the ability of a drainfield to adequately contain harmful sewage constituents above the water table decreases due to the limited filtering and adsorbing capacity of soils. Some constituents from septic sewage such as nitrate, sulfate, and chloride can move freely down to the water table even when drainfields are placed in appropriate soils. Proper planning in developing areas, including the review of sewage disposal alternatives and proper placement of drainfields, could prevent potential contamination of ground water.

Land disposal of wastes in the Piedmont, which includes sanitary landfills, industrial landfills, sewage and industrial waste lagoons and land application (spraying) of sewage can cause serious degradation of ground water. The ability of landfills and lagoons to prevent movement of contaminants down to the water table depends on proper design and installation of liners. Criteria to be considered in the selection of liners includes: (1) adequate thickness and retarding capacity, (2) design life with respect to corrosion, adsorbing capacity, etc., and (3) possible chemical reactions between lining material (clay, plastic, etc.) and constituents in the water. To insure adequate protection of ground water from land application or spraying of sewage, the effluent should be applied at levels at which the soil and vegetation can remove the remaining harmful constituents. All of these land disposal methods must comply to some extent with federal, state and county regulations -- which may include the monitoring of these sites or cleanup after a problem is detected.

Excessive application of synthetic fertilizers, animal waste fertilizers, and pesticides over agricultural land in the Piedmont can affect ground-water quality. Proper land management including land use planning, crop rotation, and careful application techniques can reduce the impact of these substances on ground-water quality.

Other potential sources of contamination include leaking gasoline and diesel storage tanks and pipelines, gasoline or diesel spills, highway deicing salts and animal wastes from feedlots. Gasoline or diesel spills and leaking storage tanks, although local in occurrence, can be serious hazards to ground-water supply due to suspected carcinogenic effects. Highway de-icing, already a problem in the northeastern United States, has the potential for contaminating ground water in the Piedmont of Virginia if not properly regulated. Animal wastes, when concentrated in a small area, can significantly raise nitrate levels in ground water.

Improper construction or maintenance of wells can result in contamination. Grading the land surface so that it slopes away from the well, or constructing a protective surface, such as a concrete slab around the well prevents contaminated surface runoff from entering the well. All possible sources of contaminants such as fuel storage tanks, trash dumps, septic tanks, and outhouses should be placed as far away from a well as possible and downgradient from the well.

## POTENTIAL FOR GROUND-WATER DEVELOPMENT

The plentiful recharge and large storage volume in the regolith in the Piedmont provide a large, dependable supply of ground water and offer great potential for future development providing proper management and quality-control measures are implemented. Based on a specific yield of 20 percent and an average thickness of 35 feet for the saturated regolith, a North Carolina study by Daniel and Sharpless (1983) estimated 1.5 billion gallons of ground water are available from storage per square mile in the Piedmont of North Carolina. Using a specific yield of 8 percent from a Maryland study by Nutter and Otton (1969) and the same saturated regolith thickness (35 feet), the calculated value is about 600 million gallons per square mile of Maryland Piedmont. The amount of ground water present in the Piedmont of Virginia is probably in the range of the numbers from neighboring states.

Estimates of recoverable ground water in areas of the Piedmont could be obtained by conducting detailed hydrologic budget studies (see Trainer and Watkins, 1975). Measurement of streamflow, precipitation, and water-table fluctuations can be used to calculate the potential volume of ground water that can safely be withdrawn without adversely affecting ground-water and surface-water supplies. A network of gages and observation wells used in such a study could be used in the future to predict potential water shortages so that preventive measures could be implemented to protect this ground-water reservoir.

Ground water offers several advantages over surface water in the development of water resources. These advantages include:

(1) continued use of land (i.e., no dams and reservoirs built);

(2) little or no treatment required (natural filtration, no problems with suspended solids);

(3) no water loss due to evaporation from surface reservoirs;

(4) low capital investment and ability to expand water supply system as needed;

(5) lower susceptibility to drought-related shortages.

The most common use of ground water in the Piedmont of Virginia is for rural domestic supply. However, as urban areas grow and more of the population shifts to rural areas, demand for water will grow. Management of ground water in the Piedmont could include: (1) reserving tracts of land for ground water development, (2) installing well fields in areas of highest potential yields, (3) protecting well fields and recharge areas from contamination, and (4) determining the optimal use of ground water in conjunction with surface-water supplies.

Development of the high-yielding limestone conglomerate and fractured siltstone units of the sedimentary basins has the potential for supplying significant quantities of water. Some municipalities in the Culpeper basin are already using ground-water from these units. However, the exploration, greater drilling, and treatment costs reduce the incentive for small water users.

## SUMMARY

The Piedmont of Virginia has an abundant supply of ground water, perhaps as much as 1.5 billion gallons are available from storage per square mile, suitable for domestic and small supply needs. The source of ground water is precipitation. Ground water is available from saprolite overlying bedrock and from fractures within the bedrock. Wells placed in draws and valleys are likely to be more productive than wells located on hilltops. Water quality throughout the crystalline terrane is suitable for nearly any need. Water quality within the sedimentary basins may not meet quality requirements, especially in deeper wells (>500 feet) where dissolved solids may exceed tolerable limits. A greater understanding of the ground-water system in the Virginia Piedmont could be used to anticipate future shortages so that preventive measures could be implemented to protect the ground-water reservoir.

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